MALCOLM PIRNIE

Technical Memorandum

Date: December 22, 2008

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Re: Estimating the Common Half Life for Legacy Sediments in Lower Passaic River

Summary

A first-order regression model was applied to the excess chemical concentrations[1] and estimated time of deposition in the Lower Passaic River, in order to determine a common half-life for legacy contaminated sediments. The data used in the model came from the high resolution cores in the Lower Passaic River and concentrations observed for the external sources. The chemicals included in the model were: trans-chlordane, 2,3,7,8-TCDD, Total PCB, 4,4'-DDE, Mercury, Lead, and Copper. The results of the analysis indicate a common decay process[2] for these sediments at an average half-life of ~ 35 years. The 95 percent confidence interval for this common half life is from 27 to 48 years. Although only seven chemicals were included in the model, this result also applies to other particle reactive contaminants in the Lower Passaic River that have a significant resuspension source term.

Objectives

- Determine whether the chemical specific decay rates or half-lives on the excess concentrations are similar (i.e., no significant difference amongst them).
- Estimate the common decay rate for the excess concentrations in legacy sediment in the Lower Passaic River, along with the associated confidence interval.

Methods

- The chemicals included in the analysis were: trans-chlordane, 2,3,7,8-TCDD, Total PCB, 4,4'-DDE, Mercury, Lead, and Copper.
- High-resolution core data from 1980 to 2007 were used in the analysis.

[1] Excess chemical concentrations were defined as the Lower Passaic sediment concentrations less the concentrations from the external sources.

[2] The term decay is used here to quantify the net processes that result in the decline of chemical concentrations over time as observed in the high resolution cores.

- A multiple regression analysis was conducted to determine the similarities and difference amongst the half-lives of the various chemicals. This model combined the excess concentrations and time of deposition for all the chemicals. In addition, it included indicator variables for the chemical type, and allowed for interaction effects between deposition time and chemical type. The first-order regression model used was:

$$\log_e ExC_i = \beta_0 + \beta_1 T_i + \beta_2 Chl_i + \beta_3 PCB_i + \beta_4 DDE_i + \beta_5 Hg_i + \beta_6 Cu_i + \beta_7 Pb_i + \beta_8 T_i Chl_i + \beta_9 T_i PCB_i + \beta_{10} T_i DDE_i + \beta_{11} T_i Hg_i + \beta_{12} T_i Cu_i + \beta_8 T_i Pb_i + \varepsilon_i$$

Where:

$\log_e ExC_i$ = natural logarithm of the excess chemical concentrations (i.e., high resolution core concentrations less external levels from head of tide, tributaries and CSO/SWOs)

$\beta_0 \ldots \beta_{13}$= regression coefficients

T_i = estimated deposition time from high resolution core dating

Chl_i = indicator variable = 1 if chemical is trans-chlordane, 0 otherwise

PCB_i = indicator variable = 1 if chemical is Total PCB, 0 otherwise

DDE_i = indicator variable = 1 if chemical is 4,4'-DDE, 0 otherwise

Hg_i = indicator variable = 1 if chemical is mercury, 0 otherwise

Cu_i = indicator variable = 1 if chemical is cupper, 0 otherwise

Pb_i = indicator variable = 1 if chemical is lead, 0 otherwise

$T_i Chl_i$, $T_i PCB_i$, $T_i DDE_i$, $T_i Hg_i$, $T_i Cu_i$, $T_i Pb_i$ = interactions effects between time of deposition and chemical type

Although there are seven chemicals, only six indicators were included (indicator variable for 2,3,7,8-TCDD not included). In the statistical theory of qualitative predictor variables, a qualitative variable of c classes is always represented by c-1 indicators variables to avoid computational difficulties. In this application, the regression for 2,3,7,8-TCDD can be represented by all other indicator values being equal to zero. Note that the exclusion of the 2,3,7,8-TCDD does not affect model results. If the indicator variable of any the other chemicals modeled was excluded, the same regression results will be obtained.

- If the regression coefficients of the interaction terms are not statistically significant, then it can be concluded that the regression lines between natural

logarithm of excess concentrations versus time for the individual chemicals are parallel, and that a common decay process occurs.

Results

Table 1 presents the regression output for the first order model described above. A statistically significant model was obtained ($p < 0.001$ from Analysis of Variance results,). The most important finding from this regression analysis is that the interaction terms are not significant ($p > 0.05$). Therefore, the individual chemical regressions are parallel and there is a common decay process for the legacy contaminated sediments in the Lower Passaic River. This legacy sediment represents the resuspension source that is the dominant contribution for most chemicals. Note that the residuals of this regression satisfy the regression assumptions of normality and homogeneity of variance.

Given that a common decay process exist for the Lower Passaic River excess legacy chemical concentrations, a second regression run was conducted to estimate the common decay rate and corresponding half-life. For this regression run, the interaction terms which are not statistically significant were dropped from the regression equation. Table 2 and Figure 1 present the results for this reduced regression output. This reduced model and all the regression coefficients are statistically significant ($p < 0.0001$), and the chemical specific regressions lines are approximately parallel. The residuals of this reduced regression satisfy the regression assumptions of normality and homogeneity of variance. The regression coefficient for the time of deposition (β_1) under the reduced regression model, which represents the common decay rate is -0.02 (Table 2). This common decay rate corresponds to a half life of ~35 years. Using the standard error and t-values from Table 2 forβ_1, the 95 percent confidence interval for β_1 is -0.026 to -0.014. The corresponding common half-life confidence interval is 27 to 48 years.

Table 1: Regression results with interaction terms

Multiple Regression Analysis

Dependent variable: LN_C

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	52.9204	16.7403	3.16126	0.0017
T	-0.0270905	0.00838435	-3.23107	0.0014
Chlo	-35.7128	23.5131	-1.51885	0.1299
Hg	-12.2543	21.4993	-0.569985	0.5692
DDE	23.2896	24.151	0.964335	0.3357
Pb	-12.8332	21.4993	-0.596913	0.5511
Cu	-23.8338	21.4993	-1.10858	0.2686
PCB	7.29054	23.5131	0.310063	0.7567
T_Chlo	0.0200792	0.0117754	1.70518	0.0893
T_Hg	0.00696226	0.0107712	0.646376	0.5186
T_DDE	-0.00903859	0.0120967	-0.747197	0.4556
T_Pb	0.00957072	0.0107712	0.888546	0.3750
T_Cu	0.0149399	0.0107712	1.38702	0.1666
T_PCB	0.000407156	0.0117754	0.0345769	0.9724

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1834.02	13	141.078	978.15	0.0000
Residual	39.663	275	0.144229		
Total (Corr.)	1873.68	288			

R-squared = 97.8832 percent
R-squared (adjusted for d.f.) = 97.7831 percent
Standard Error of Est. = 0.379775
Mean absolute error = 0.283226

Table 2: Regression results without interaction terms

Multiple Regression Analysis

Dependent variable: LN_C

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	38.7251	5.7386	6.74818	0.0000
T	-0.0199807	0.002874	-6.95222	0.0000
Chlo	4.38214	0.0919774	47.6436	0.0000
Hg	1.64672	0.0857078	19.2132	0.0000
DDE	5.24658	0.0932575	56.2591	0.0000
Pb	6.27178	0.0857078	73.1763	0.0000
Cu	5.98301	0.0857078	69.8071	0.0000
PCB	8.1009	0.0919774	88.0748	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1832.76	7	261.822	1797.79	0.0000
Residual	40.9236	281	0.145636		
Total (Corr.)	1873.68	288			

R-squared = 97.8159 percent
R-squared (adjusted for d.f.) = 97.7615 percent
Standard Error of Est. = 0.381622
Mean absolute error = 0.283729

Figure 2: Illustration of natural logarithm of observed excess chemical concentration, time of deposition and fitted Regression Function.